# Energy balance at high altitude of 6,542 m.

# Energy balance at high altitude of 6,542 m

KLAAS R. WESTERTERP, BENGT KAYSER, LOEK WOUTERS, JEAN-LOUIS LE TRONG, AND JEAN-PAUL RICHALET

*Department of Human Biology, University of Limburg, 6200 MD Maastricht, The Netherlands; Départment de Physiologie, Centre Médical Universitaire, 1211 Geneva 4, Switzerland; and Association pour la Recherche en Physiologie de l'Environnement, F-93012 Bobigny cedex, France*

**Westerterp, Klaas R., Bengt Kayser, Loek Wouters, Jean-Louis Le Trong, and Jean-Paul Richalet.** Energy balance at high altitude of 6,542 m. *J. Appl. Physiol.* 77(2): 862–866, 1994.—Weight loss due to malnutrition and possibly intestinal malabsorption is a well-known phenomenon in high-altitude climbers. Up to ~5,000 m, energy balance may be attained and intestinal energy digestibility remains normal. To see whether *1*) energy balance may also be attained at 6,542 m and, if not, *2*) whether decreased energy digestibility would play a significant role in the energy deficit, energy intake (EI), energy expenditure, body composition, and energy digestibility of 10 subjects (4 women, 6 men; 27–44 yr) were assessed during a 21-day sojourn on the summit of Mt. Sajama, Bolivia (6,542 m). EI was measured during two 3-day intervals: EI1 (*days 7–9*) and EI2 (*days 17–19*). Total fecal energy loss during EI1 was calculated from fecal energy measured by bomb calorimetry. Average daily metabolic rate (ADMR) at altitude was measured in six subjects (2 women, 4 men) using doubly labeled water over a 10-day interval (*days 9–19*). Basal metabolic rate was measured before and after the expedition by respiratory gas analysis. Body composition was estimated from skinfolds and body mass before and during the altitude sojourn. Subjects were in negative energy balance throughout the observation period (EI1 − ADMR = −2.9 ± 1.8 MJ/day and EI2 − ADMR = −2.3 ± 1.8 MJ/day based on a gross energy digestibility of 95%). The activity level, expressed as ADMR to basal metabolic rate, was 1.56–2.39. The loss of fat mass (3.7 ± 1.5 kg) represented 74 ± 15% of the loss of body mass. Energy content of the feces was 21 kJ/g dry wt, and gross energy digestibility amounted to 85%. The energy deficit increased to 3.5 MJ/day after correction for the decreased energy digestibility. In conclusion, energy balance was not attained at 6,542 m. The resulting energy deficit appeared to result mostly from malnutrition, and only a limited part could be attributed to malabsorption.

energy intake; digestibility; malabsorption; energy expenditure; body composition; doubly labeled water

WEIGHT LOSS at high altitude is a well-known phenomenon. Many studies have shown subjects to lose significant amounts of fat mass (FM) as well as fat-free mass (FFM) during a climb to and/or a stay at altitudes of ≥3,600 m. The amount lost seems to depend on the altitude reached and the time spent there (1, 6–8, 14, 16, 17, 19). Several hypotheses have been formulated to explain this phenomenon, e.g., simple malnutrition, loss of body water, and intestinal malabsorption (for review see Ref. 10).

With regard to malnutrition, there is evidence that subjects can maintain energy balance during a stay at high altitude. Consolazio et al. (3) transported six healthy young men from sea level to 4,300 m for a 6-day period, supplying them with a constant diet of ~16 MJ/day, of which one-half was in liquid form and the remainder was solid foods with a 3-day rotating menu. Overall mean body weight loss was only 1 kg, and nitrogen balances were slightly positive, indicating that the subjects did not lose muscle mass. Butterfield et al. (2) studied seven healthy men before and while they were subjected to a 3-wk stay at 4,300 m, giving them access to the same diet at sea level and altitude and increasing intake at altitude to accommodate any increased needs. There was a mean body weight loss of 2.1 ± 1.0 kg over the 3-wk period, but the rate of weight loss significantly diminished from 201 ± 75 g/day over the 1st wk to 72 ± 48 g/day over the last week. Also during a 1-mo stay at 5,050 m, it was recently shown that, in the presence of sufficient comfort and palatable food, weight loss can be largely prevented (11).

With regard to malabsorption, it appears that at ≤5,000–5,500 m intestinal absorptive function for macronutrients remains normal (2, 9, 10, 12). The available evidence at higher altitude (>6,300 m) on three subjects during a Mt. Everest expedition is not very strong (1), and it remains unclear whether malabsorption would play a significant role for energy balance at altitudes of >5,500 m.

The present study was therefore designed to complement the foregoing studies on energy metabolism at very high altitude. The primary aim of the study was to test the hypothesis that energy balance can also be maintained at an altitude of 6,542 m. The secondary aim of the study was to test the hypothesis that, in case energy balance could not be maintained, a decrease in energy digestibility would explain, at least in part, the energy deficit observed. To these aims energy intake (EI), energy expenditure, body composition, and energy digestibility of 10 subjects were assessed during a 21-day sojourn on the summit of Mt. Sajama (6,542 m).

## METHODS

The subjects were four women and six men aged 35 ± 6 (SD) yr, with body mass index of 22.0 ± 1.5 $kg/m^2$. Nine subjects were medical doctors, and one was a medical engineer; all had previous high-altitude experience (maximum altitude reached ranging from 4,350 to 8,760 m). Nine subjects were sea-level natives and one (*subject 1*) was born at 3,600 m but resided at sea level for 5 yr before participating in this study. None of the subjects was acclimatized to high altitude at the start of the experiment. The observations started with baseline measurements at sea level (Paris, France and Maastricht, The Netherlands). Subjects subsequently traveled to La Paz, Bolivia (3,600 m), where they stayed for 5 days to acclimatize and to further organize the expedition. Subsequently, the remaining altitude change from 3,600 to 6,542 m was covered in 13 days. The stay in tents on the large flat summit of Mt. Sajama (6,542 m) lasted 21 days (Fig. 1). During the stay on the summit, the activity level of the subjects was low. They spent most of the time reading and taking care of the camp (e.g., melting snow, cooking,

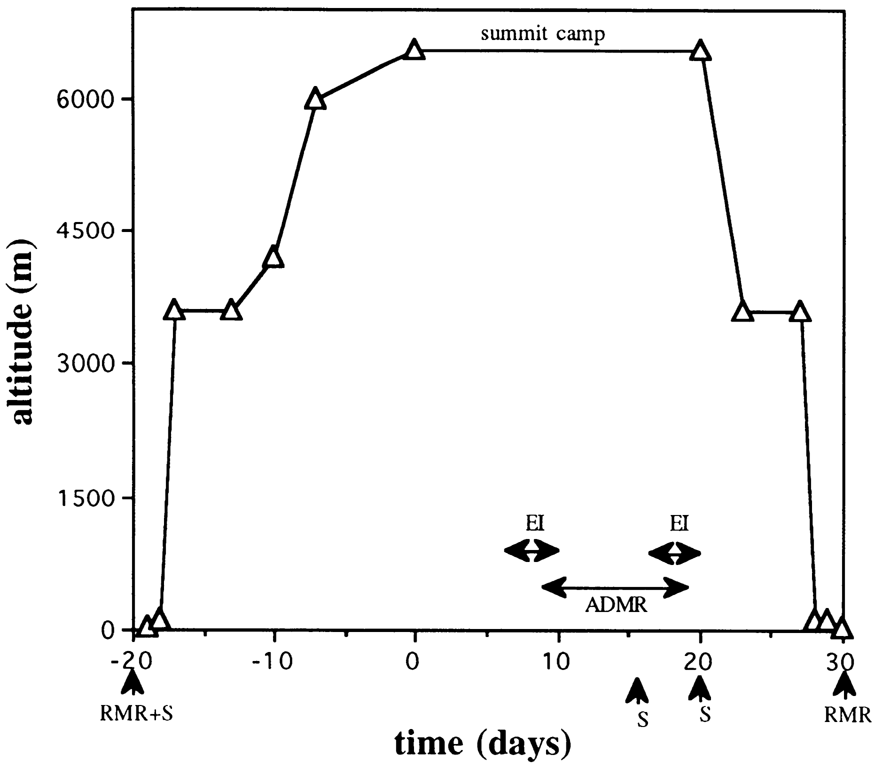


FIG. 1. Altitude profile of subjects during expedition on Mt. Sajama. Arrows, observation interval of energy intake (EI), average daily metabolic rate (ADMR), measurement of resting metabolic rate (RMR), measurement of body composition from skinfold thickness (S), and RMR + S.

and fixing tents) and underwent altogether four exercise tests on a cycle ergometer. Mean ambient temperature during the stay at 6,542 m was −13°C. The temperature in the laboratory tent during the experiments varied between 14 and 19°C. Finally, sea-level observations were again performed on return to Paris and Maastricht 10 days after leaving the summit. Energy balance was determined after the initial acclimatization by measuring EI and energy expenditure. The resulting data on energy balance were then related individually to changes in body composition.

EI at altitude was measured with a dietary record over two 3-day intervals: *days 7–9* (EI1) and *days 17–19* (EI2). Subjects were trained by a dietician before the study to record their food intake and fluid intake in a diary, including brand names and cooking recipes where appropriate. Food items were weighed with a table scale in most cases, and volumes were measured with a graduated container. After the expedition, the dietician examined the diary with the subject to clarify and eliminate inconsistencies. The energy content [metabolizable energy = gross energy (GE) − fecal energy − urinary energy] of the food intake was then derived from food tables, and the percentages of carbohydrate, fat, and protein intakes were calculated (13). From these data, the GE content of the diet (which includes undigestible material, i.e., cellulose) was calculated using Atwater's factors for the heat of combustion (22). To determine nutrient absorption and nitrogen balance, subjects collected 24-h urine samples for 1 day and total feces for all days of EI1. Subjects ingested a gelatin capsule containing Brilliant Blue before the first meal and after the last meal of the 3-day interval to mark the beginning and end of the period of fecal collection as described before (12). Total feces production was weighed and homogenized with an equivalent weight of water. Sulfuric acid (30 g) was added to bring pH down to <3 to prevent formation of $NH_3$. The 24-h urine sample was measured by volume and was acidified to pH of <3. Ten-milliliter samples of both feces and urine were taken for further analysis. Energy content of the feces was measured with an adiabatic bomb calorimeter (model C-400, IKA Kalorimeter, Janke). Nitrogen content of the feces and urine was measured with a type CHN-O-rapid Heraeus analyzer.

Energy expenditure was measured under resting postabsorptive conditions [resting metabolic rate (RMR)] at sea level and under field conditions [average daily metabolic rate (ADMR)] at altitude. Sleeping metabolic rate (SMR) as a measure for RMR was observed before the expedition during an overnight stay in a respiration chamber as described before (15, 20). Subjects entered the respiration chamber at 1830 h, after they had their last meal of the day. No food was consumed in the chamber, and coffee or tea was allowed until 2200 h. SMR was measured from 300 to 600 h at the minimal activity level judged from Doppler radar observation. Basal metabolic rate (BMR) as a measure for RMR was subsequently measured. Subjects got up between 700 and 800 h, dressed, and walked slowly to a ventilated hood system in the same building. After a 15-min supine rest, BMR was measured during three consecutive 5-min intervals. At altitude, ADMR was measured with doubly labeled water, as described before (18, 21), in 2 women and 4 men randomly selected among the 10 subjects. The observation interval lasted 10 days, from *day 9* to *day 19* of the stay at the summit. Subjects were given a weighed dose of water with a measured enrichment of ~5 atom% $^2H$ and 10 atom% $^{18}O$ so that baseline levels were increased to 150 and 300 ppm for $^2H$ and $^{18}O$, respectively. To allow for corrections due to changes in baseline abundances, the remaining subjects (2 women, 2 men) collected urine samples over the observation interval without getting an isotope dose. Urine samples for isotope measurement were collected before dosing at night; from the second voiding on the next morning; and after 2, 4, 6, 8, and 10 days. Isotope abundances in the urine samples were measured with an isotope-ratio mass spectrometer (VG Isogas, Aqua Sira). $CO_2$ production was calculated from isotope elimination rates as calculated from the slope of the elimination curve, correcting for changes in body water as measured with $^2H$ dilution at the start and end of the observation interval. At the end of the ADMR measurements, subjects were given a weighed dose of water with a measured enrichment of ~5 atom% $^2H$ so that the body water level was increased with 100 ppm for $^2H$. Urine samples for isotope measurement were collected before dosing at night and from the second voiding on the next morning, 8–10

TABLE 1. *TBW, fractional elimination rates from body water of excess $^{18}O$ and $^{2}H$, fluid$_{in}$, fluid$_{out}$, EI, and ADMR*

| Subj No. | TBW, liters | $k_{18}$, day$^{-1}$ | $k_2$, day$^{-1}$ | Fluid$_{in}$, l/day | Fluid$_{out}$, l/day | EI, MJ/day | ADMR, MJ/day |
|---|---|---|---|---|---|---|---|
| *1* | 28.7 | 0.12670 | 0.09974 | 1.4 | 2.9 | 6.4 | 9.2 |
| *3* | 47.1 | 0.10188 | 0.07839 | 2.6 | 3.7 | 12.7 | 13.1 |
| *5* | 54.7 | 0.08652 | 0.06220 | 2.4 | 3.4 | 14.0 | 15.3 |
| *6* | 43.1 | 0.07351 | 0.05150 | 1.7 | 2.2 | 8.5 | 12.1 |
| *8* | 32.4 | 0.11073 | 0.08450 | 1.6 | 2.7 | 5.7 | 8.8 |
| *10* | 46.8 | 0.08951 | 0.06854 | 2.1 | 3.2 | 7.7 | 12.1 |
| Mean ± SD | 42.1±9.8 | 0.09814±0.01900 | 0.07415±0.01713 | 2.0±0.5 | 3.0±0.5 | 9.2±3.4 | 11.8±2.4 |

TBW, mean total body water as calculated from initial and final isotope dilution space; $k_{18}$ and $k_2$, fractional elimination rates from body water of excess $^{18}O$ and $^{2}H$, respectively; Fluid$_{in}$, fluid intake; Fluid$_{out}$, fluid output; EI, energy intake; ADMR, average daily metabolic rate.

h after dosing. $CO_2$ production was converted to ADMR using an energy equivalent based on the individual macronutrient composition of the diet and the use of body fat reserves. In an attempt to monitor changes in body composition in the absence of underwater weighing facilities in the field, percent body fat and lean body mass were estimated according to Durnin and Womersley (5).

Results are presented as means ± SD unless otherwise stated. Values obtained before, during, and after the stay on Mt. Sajama were compared with Wilcoxon's signed-rank test. Data on energy balance were related to changes in body composition using linear regression and Pearson's correlation coefficients.

## RESULTS

The mean composition of the diet at altitude expresssed as percentage of EI was 54 ± 6, 14 ± 2, and 31 ± 6% for carbohydrate, protein, and fat, respectively. Differences between EI1 and EI2 were not systematic and were <2%, suggesting a constant diet with respect to the macronutrient composition. The actual energy substrate for the energy expenditure, necessary for the calculation of the energy expenditure from the measured $CO_2$ production, was different from the diet composition because the subjects were not in energy balance (see below). Mean EI showed a nonsignificant increase from 7.8 ± 3.1 MJ/day in EI1 to 8.2 ± 3.5 MJ/day in EI2 at the start and end, respectively, of the observation interval of ADMR with doubly labeled water. The overall mean EI, calculated as the average of both values, was 8.0 ± 3.2 MJ/day based on standard values for nutrient absorption. Mean fluid intake over EI1 and EI2, including water in drinks as well as water in the food, was 1.9 ± 0.5 and 1.8 ± 0.5 l/day, respectively.

The energy content of the feces was 20.6 ± 1.7 kJ/g dry wt (range of 18.0–23.0 kJ/g). The total energy loss in the feces from the food consumed in the 3-day observation period was 3.6 ± 1.3 MJ. The GE content of the food consumed over the interval was 25.2 ± 9.8 MJ. Combining these two values, the average energy digestibility amounted to 85.2 ± 4.7%.

The combination of the dietary record with the nitrogen output in feces and urine allowed calculation of protein digestion and balance. Protein digestion was 88.6 ± 3.8%. Protein balance was −28.6 ± 24.2 g/day based on the measured protein digestion. The value for protein balance based on the dietary record and urine nitrogen output using the standard value for protein digestion from the food tables was similar (−26.3 ± 24.5 g/day).

Background isotope levels were 142.4 ± 0.6 and 1,986.9 ± 0.9 ppm for $^{2}H$ and $^{18}O$, respectively, at the first measurement 4 days after reaching the summit, well below the mean level of 151.0 ± 0.8 and 1,999.0 ± 1.1 ppm for $^{2}H$ and $^{18}O$, respectively, measured at sea level in Maastricht. The background values showed a further significant decrease to 141.3 ± 0.8 ppm $^{2}H$ and 1,985.0 ± 1.2 ppm $^{18}O$ on *day 9* at the start of the doubly labeled water observation. Background values showed no further changes afterward, being 141.3 ± 0.9 and 1,984.6 ± 1.2 ppm for $^{2}H$ and $^{18}O$, respectively, in the control subjects at the end of the observation period. Therefore, water loss and $CO_2$ production could be calculated from isotope elimination rates without corrections for a changing baseline. Water loss and energy expenditure as calculated from isotope elimination are presented in Table 1. Comparing water loss with water input needs correction of water intake for metabolic water (see DISCUSSION). ADMR did not show a systematic change over the 10-day observation period. Mean values over subsequent 2-day intervals were 11.0 ± 3.7, 11.5 ± 1.4, 12.6 ± 3.7, 12.3 ± 3.5, and 11.1 ± 2.0 MJ/day, respectively. ADMR was higher than EI in all subjects; the mean difference was 24 ± 14% of ADMR. There was a good agreement between SMR and BMR measured before the expedition. SMR was slightly lower than BMR, but the difference of 2 ± 4% was not significant. Comparing BMR values before and after the expedition, differences were insignificant (mean difference −3 ± 7%).

Body mass and body composition were different before and after 20 days at 6,542 m (Table 2). Body mass decreased by 4.9 ± 2.0 kg ($P < 0.01$), and FM decreased by 3.5 ± 1.5 kg ($P < 0.01$). The decrease in FFM of 1.3 ± 2.3 kg was not significant. However, changes in body composition as estimated during the stay at altitude with skinfold thickness measurements have to be interpreted with some care (7). One subject (*subject 8*) showed indications of altitude edema. This fact probably influenced the accuracy of the skinfold thickness as a measure for body fat; therefore this measurement for *subject 8* was excluded from further analysis.

## DISCUSSION

Water balance over the observation interval can be calculated from fluid input and output, correcting the former for metabolic water production. Metabolic water production was calculated from dietary intake and catabolism of body stores according to Consolazio et al. (3).

TABLE 2. *BM, BF, SMR, and BMR before and after high-altitude exposure*

| Subj No. | Before Exposure BM, kg | BF, % | SMR, MJ/day | BMR, MJ/day | After Exposure BM,* kg | BF,* % | BMR,† MJ/day |
|---|---|---|---|---|---|---|---|
| *1* | 49.5 | 27.1 | 5.11 | 5.23 | 48.0 | 23.4 | |
| *2* | 54.8 | 26.2 | 5.05 | 5.04 | 49.0 | 20.5 | 5.43 |
| *3* | 71.0 | 13.3 | 7.70 | 7.32 | 66.5 | 12.3 | 7.46 |
| *4* | 64.6 | 14.9 | 6.16 | 6.25 | 60.0 | 11.0 | 6.08 |
| *5* | 76.4 | 14.6 | 6.42 | 6.51 | 69.0 | 11.3 | 6.31 |
| *6* | 70.0 | 17.0 | 6.22 | 6.42 | 61.5 | 12.6 | 6.74 |
| *7* | 67.6 | 26.2 | 5.59 | 6.16 | 63.5 | 18.0 | |
| *8* | 58.4 | 27.6 | 6.00 | 6.09 | 55.0 | 25.5 | 5.23 |
| *9* | 63.8 | 21.6 | 5.96 | 5.99 | 60.5 | 14.0 | 5.52 |
| *10* | 80.5 | 18.8 | 7.00 | 7.32 | 75.0 | 15.0 | 6.62 |
| Mean ± SD | 65.7±9.6 | 20.7±5.7 | 6.12±0.81 | 6.23±0.74 | 60.8±8.5 | 16.4±5.2 | 6.17±0.76 |

BM, body mass; BF, body fat as calculated from skinfold thickness; SMR, sleeping metabolic rate as measured overnight in respiration chamber; BMR, basal metabolic rate as measured in early morning with ventilated hood. Missing values of BMR after expedition were due to nonavailability of subjects for practical reasons. * After 20 days at 6,542 m. † 10 Days after descent from 6,542 m (2 days after descent from 3,600 m).

Thus, there was no significant difference between water input and output, i.e., subjects were in water balance. However, water balance was reached at a low level of water turnover. The present water output of 3.0 ± 0.5 l/day was lower than the value of 3.5 ± 0.2 l/day for water input plus metabolic water reported in six men during a 6-day stay at 4,300 m (3). The values for water input are much lower than ≥4.2 l/day, as reported in seven men during a 3-wk stay at 4,300 m (2). Water turnover was probably limited by a reduced water input due to the low water availability and was comparable to the value of 3.3 ± 0.6 l/day measured during climbing between 5,000 and 8,872 m on Mt. Everest (24).

Energy balance can be calculated from EI as measured with the dietary record and energy expenditure as measured with doubly labeled water. Mean EI, the average over 3 days at the start and end of the 10-day observation period with doubly labeled water, was 2.6 ± 1.5 MJ/day lower than energy expenditure. There was a tendency for an increase in EI, probably as a result of a reduction in symptoms of acute mountain sickness (AMS). AMS was determined by scoring cerebral symptoms, digestive symptoms, fatigue symptoms, and sleep symptoms on a four-point scale, where 0 meant no symptoms (13a). AMS scores dropped from 3.6 ± 1.6 during EI1 to 1.9 ± 1.4 during EI2 ($P < 0.05$). However, energy expenditure did not show any systematic change over the 10-day observation interval. Thus, there was only a trend to a balance between EI and energy expenditure over the 3-wk stay at 6,542 m, leaving on average a gap of ≥2.3 MJ/day or 20% of ADMR.

The observed digestibility of 85% was lower than that usually measured at sea level (94%; Refs. 2, 22), at 4,300 m (95%; Ref. 2), or at 5,050 m (96%; Ref. 12). Also, the calculated protein digestion (89%) was lower than that reported at 5,050 m (96%; Ref. 12). Therefore, at first glance it appears that the subjects of this study indeed experienced a certain degree of intestinal malabsorption. However, the energy content of the feces of the subjects (21 kJ/g dry wt) was actually lower than that reported for a mixed diet at sea level (22 kJ/g dry wt; Ref. 4) and the same as that measured at 5,050 m (12) for a diet of similar macronutrient and fiber composition, suggesting, on the contrary, a normal intestinal absorptive capacity. Thus, the energy content of the feces seems to exclude significant malabsorption of fat or other macronutrients. The above evidence of malabsorption should therefore be interpreted with care, and additional experiments seem necessary before the hypothesis of malabsorption at ≥6,300 m can be accepted.

If one accepts the observed value for digestibility, it can be calculated that the mean difference between intake and expenditure increased from −2.6 ± 1.5 to −3.5 ± 2.4 MJ/day. It thus appears that even if some degree of malabsorption would indeed develop at altitudes of ≥6,300 m (1), it would be relatively small compared with the energy deficit resulting from simple malnutrition. In fact, the energy deficit of 2.6 MJ/day amounted to ~24% of ADMR. During a climb of Mt. Everest, the energy deficit was found to increase to 6.1 MJ/day or ~45% of ADMR, and most of this was due to an important decrease of EI (19).

Body weight decreased by 4.9 ± 2.1 kg, representing on average 74% body fat from before to after 20 days at 6,542 m. Fulco et al. (7) recently stated that the skinfold method was not acceptable for the measurement of body composition at altitude. Indeed, as indicated by total body water measurements, one of the subjects in this study showed peripheral subcutaneous edema and had to be excluded from the analysis. On the other hand, the results of the protein balance can be used to estimate changes in FFM. If we assume an FFM hydration of 73%, the measured mean protein loss of 26–28 g/day would suggest an FFM loss of 96–104 g/day. This is a maximum estimate, since there are indications for a decrease of the hydration of FFM at altitude. When the maximum downward correction of the hydration of FFM is applied, the estimated FFM loss is 94–101 g/day (11).

It is not possible to calculate the energy equivalent of changes in body mass from the discrepancy between EI and energy expenditure. It is only possible to estimate the energy equivalent, as intake and expenditure were only measured simultaneously over the second half of the 3-wk stay at 6,542 m. Extrapolating the mean daily energy deficit of 2.6 MJ over *days 9–19* to the 10-day ascent interval up to *day 20* at 6,542 m results in an energy deficit of 78 MJ compared with a loss of 3.6 kg FM and 1.2 kg FFM. Of course, this is an absolute minimum for the energy deficit. Mean EI was only 4.6 MJ/day during the ascent period, whereas during that time energy expenditure was probably higher than the mean value of 11.8 MJ/day measured over *days 9–19*. Thus, the mean energy loss from the body reserves of ~150 MJ over the mentioned interval of 30 days, assuming an energy equivalent of 39 MJ/kg FM and 5 MJ/kg FFM, can be explained.

The activity level of the subjects can be calculated by expressing ADMR as a multiple of BMR, the physical activity index (PAI). If we assume that BMR over *days 9–19* at 6,542 m was the same as that at sea level and average BMR values before and after the expedition, the mean PAI was 1.84 ± 0.28 (range of 1.56–2.39). This value falls just outside the range of 1.5–1.8 for light to moderately active subjects (23) but is lower than the mean PAI of 2.2 measured during climbing at high altitude (19). Of course, the PAI value has to be interpreted with some care; as at high altitude, BMR was shown to have increased. Butterfield et al. (2) measured an increase of BMR during a 21-day stay at 4,300 m of 10–15% compared with sea-level values. Whatever happened with BMR at 6,542 m, ADMR was relatively high for subjects with a sedentary life style, living in tents and occasionally getting out in the close surroundings.

In conclusion, the results from this study indicate that subjects with ad libitum access to food do not attain energy balance during a 3-wk sojourn at 6,542 m. EI is low, whereas energy expenditure reaches values comparable to those for moderate activity at sea level. The resulting energy deficit appears to be due mostly to malnutrition and only a limited part can be attributed to malabsorption.

We are indebted to the participants of the study: Ana-Maria Antezana, Hélène Barthélémy, Vincent Bonaldi, Patrick Bouchet, Emmanuel Cauchy, Jean-Bernard Duchemin, Jean-Louis Le Trong, Michèle Marchal, Chantal Para, and Jean-Paul Richalet. Isabelle Faivre of the Physiology Laboratory of the Medical Faculty of Besançon, France, analyzed the food records.

The study was supported by grants from Sandoz Nutrition, France and Switzerland; and the Groupe de réflexion sur le problème de l'eau dans les environnements d'exception, Paris, France.

Address for reprint requests: K. R. Westerterp, Dept. of Human Biology, Univ. of Limburg, PO Box 616, 6200 MD Maastricht, The Netherlands.

Received 10 December 1992; accepted in final form 21 March 1994.

## REFERENCES


1. **Boyer, S. J., and F. D. Blume.** Weight loss and changes in body composition at high altitude. *J. Appl. Physiol.* 57: 1580–1585, 1984.
2. **Butterfield, G. E., J. Gates, S. Sharon, G. A. Brooks, J. R. Sutton, and J. T. Reeves.** Increased energy intake minimizes weight loss in men at high altitude. *J. Appl. Physiol.* 72: 1741–1748, 1992.
3. **Consolazio, C. F., H. L. Johnson, H. J. Krzywicki, and T. A. Daws.** Metabolic aspects of acute altitude exposure (4,300 meters) in adequately nourished humans. *Am. J. Clin. Nutr.* 25: 23–29, 1972.
4. **Diem, K., and C. Lentner.** *Wissenschaftliche Tabellen.* Basel: Geigy, 1971, p. 653–656.
5. **Durnin, J. V. G. A., and J. Womersley.** Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged 16–72 years. *Br. J. Nutr.* 32: 77–97, 1974.
6. **Fulco, C. S., A. Cymerman, N. A. Pimental, A. J. Young, and J. T. Maher.** Anthropometric changes at high altitude. *Aviat. Space Environ. Med.* 56: 220–224, 1985.
7. **Fulco, C. S., R. W. Hoyt, C. J. Baker-Fulco, J. Gonzalez, and A. Cymerman.** Use of bioelectrical impedance to assess body composition changes at high altitude. *J. Appl. Physiol.* 72: 2181–2187, 1992.
8. **Guilland, J. C., and J. Klepping.** Nutritional alterations at high altitude in man. *Eur. J. Appl. Physiol. Occup. Physiol.* 54: 517–523, 1985.
9. **Hannon, J. P., G. J. Klain, D. M. Sudman, and F. J. Sullivan.** Nutritional aspects of high-altitude exposure in women. *Am. J. Clin. Nutr.* 29: 604–613, 1976.
10. **Imray, C. H. E., J. Chesner, M. Winterborn, A. Wright, J. P. Neoptolemeus, and A. R. Bradwell.** Fat absorption at altitude, a reappraisal (Abstract). *Int. J. Sports Med.* 13, *Suppl.* 1: 87, 1992.
11. **Kayser, B.** Nutrition at high altitude. *Int. J. Sports Med.* 13, *Suppl.* 1: 129–131, 1992.
12. **Kayser, B., K. Acheson, J. Decombaz, E. Fern, and P. Cerretelli.** Protein absorption and energy digestibility at high altitude. *J. Appl. Physiol.* 73: 2425–2431, 1992.
13. **Randoin, L.** *Table de Composition des Aliments,* edited by J. Lanore. Paris: Lanore, 1982.

13a. **Richalet, J.-P., A.-M. Antezana, A. Bienvenu, M. Marchal, J.-C. Souberbiel, E. Cauchy, J.-L. Le Trong, M. Déchaux, R. Kacimi, V. Bonaldi, K. Westerterp, B. Kayser, and C. Dubray.** Physiological factors in survival at extreme altitude. In: *Hypoxia and Molecular Medicine,* edited by J. R. Sutton, C. S. Houston, and G. Coates. Burlington, VT: Queen City Printers, 1993, p. 235–251.

14. **Rose, M. S., C. S. Houston, C. S. Fulco, G. Coates, J. R. Sutton, and A. Cymerman.** Operation Everest II: nutrition and body composition. *J. Appl. Physiol.* 65: 2545–2551, 1988.
15. **Schoffelen, P. F. M., W. H. M. Saris, K. R. Westerterp, and F. ten Hoor.** Evaluation of an indirect calorimeter for measurement of energy balance in man. In: *Human Energy Metabolism: Physical Activity and Energy Expenditure Measurements in Epidemiological Research Based Upon Direct and Indirect Calorimetry,* edited by A. J. H. van Es. Wageningen, The Netherlands: Stichting Nederlands Insituut voor de Voeding, 1984, p. 51–54. (Eur. Nutr. Rep. 5)
16. **Stock, M. J., N. G. Norgan, A. Ferro-Luzzi, and E. Evans.** Effect of altitude on dietary-induced thermogenesis at rest and during light exercise in man. *J. Appl. Physiol.* 45: 345–349, 1978.
17. **Surks, M. I., K. S. K. Chinn, and L. O. Matoush.** Alterations in body composition in man after acute exposure to high altitude. *J. Appl. Physiol.* 21: 1741–1746, 1966.
18. **Westerterp, K. R., F. Brouns, W. H. M. Saris, and F. ten Hoor.** Comparison of doubly labeled water with respirometry at low- and high-activity levels. *J. Appl. Physiol.* 65: 53–56, 1988.
19. **Westerterp, K. R., B. Kayser, F. Brouns, J. P. Herry, and W. H. M. Saris.** Energy expenditure climbing Mt. Everest. *J. Appl. Physiol.* 73: 1815–1819, 1992.
20. **Westerterp, K. R., G. A. L. Meijer, E. M. E. Janssen, W. H. M. Saris, and F. ten Hoor.** Long-term effect of physical activity on energy balance and body composition. *Br. J. Nutr.* 68: 21–30, 1992.
21. **Westerterp, K. R., and W. H. M. Saris.** Limits of energy turnover in relation to physical performance, achievement of energy balance on a daily basis. *J. Sports Sci.* 9: 1–15, 1991.
22. **Widdowson, E. M.** Assessment of the energy value of human foods. *Proc. Nutr. Soc.* 14: 142–154, 1955.
23. **World Health Orginization.** *Energy and Protein Requirements: Report of a Joint FAO/WHO/UNU Expert Consultation.* Geneva: World Health Org., 1985. (Tech. Rep. Ser. 724)